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Security-Constrained Economic Dispatch for Integrated Natural gas and Electricity Systems

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Abstract

This paper proposes a security-constrained economic dispatch (ED) model for integrated natural gas and electricity systems. Natural gas system is modeled and its security constraints are integrated into the ED model. The Gas Shift Factor (GSF_{gas}) matrix is defined to reflect the impact of gas supply and load of each node on pipeline flow. The objective function for ED model is to minimize power system operating costs considering coal-fired generating units operating costs and natural gas-fired generating units (NGFGU) operating costs respectively. Numerical case studies with the IEEE 30-bus system integrated with a seven-node gas system demonstrate the effectiveness of the proposed ED model.

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Keywords: natural gas-fired generating units (NGFGU), integrated natural gas and electricity systems, security-constrained, economic dispatch

Nomenclature

Abbreviation

NGFGU	Natural gas-fired generating units
ED	Economic dispatch

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GSF_{gas}	Gas Shift Factor
GSF_e	Generation Shift Factor
Symbols:	
S_{max}/S_{min}	Max and min limit of gas supply
GL_{max}/GL_{min}	Max and min limit of gas load
$\overline{\pi}_i / \underline{\pi}_i$	Maximum and minimum pressure
$Limit_{gas}/Limit_e$	Gas / electricity transmission limit
a,b,c	Cost coefficients of coal-fired units
η	Fuel coefficient of gas-fired unit
Pr_{gas}	Price of natural gas
D	Power demand
P_{max}/P_{min}	Max and min power generation
RU/RD	Up and down ramp rate
RES	Spinning reserve requirement
S/ GL	Gas supply and load
π	Node press
F_{mj}	Gas flow between node m and j
F_c	Cost function of coal-fired units
P	Power generation
Subscript	
m, i, j	Gas system nodes
n	Generators
NG	Number of gas -fired power plant
t	Time period
NT	Number of time periods
NC	Number of coal -fired power plant
b	Power system buses
br	Power system branches
NB	Number of branches

1. Introduction

The natural gas consumption for power generation in the world has increased significantly in the last decade. Because of the tight coupling of the electricity system and natural gas systems, the number of NGFGU installations has grown dramatically, too [1]. Compared with conventional coal plants, NGFGU has better economic efficiency, lower environmental impacts and faster response capacities [2].

Due to the interdependence of electric power and natural gas systems, the economy and reliability of different energy systems would be influenced by each other directly [3-4]. [3] and [4] respectively analysed the impact of one system on the other using integrated model. In [5, 6], optimal operation of the integrated natural gas and electricity systems were analysed considering constraints of both systems. Therefore, for ED problem of integrated natural gas and electricity system, not only the electricity system security constraints, but also the natural gas system security constraints should be taken into account.

2. Model of Natural Gas System

This section presents the model of the natural gas system. Fig. 1 describes a seven-node natural gas system.

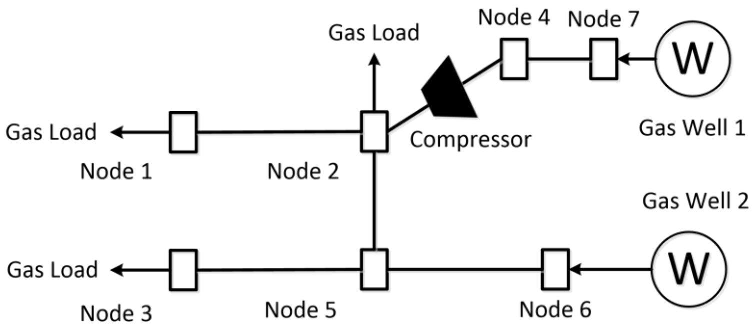

Fig. 1. Diagram of the seven-node natural gas system

1) ***Gas supply and load:*** Most of the gas is supplied by the gas wells, restricted by its upper and lower boundaries of the gas flow, which can be modeled as:

$$S_{\min} \le S \le S_{\max} \tag{1}$$

Corresponding to the upper and lower generation limits of NGFGU, the gas load is also limited as:

$$GL_{\min} \le GL \le GL_{\max} \tag{2}$$

2) ***Pipeline flow:*** The pipeline flow is determined by the characteristics of the pipeline (e.g. the length, the diameter, the operating temperature, and the pressure difference between the association nodes). The flow can be modeled as:

$$\begin{gathered} F_{m\mathrm{j}} = \mathrm{sgn}(\pi_m, \pi_j) \cdot C_{mn}\sqrt{\left|\pi_m^2 - \pi_j^2\right|} \\ \mathrm{sgn}(\pi_m, \pi_j) = \begin{cases} \mathbf{1} & \pi_m \ge \pi_j \\ \mathbf{-1} & \pi_m < \pi_j \end{cases} \end{gathered} \tag{3}$$

$$\underline{\pi}_i \le \pi_i \le \overline{\pi}_i \tag{4}$$

In fact, the flow in one pipeline is related to the supply and load with virtually no loss. This paper defines the GSF_{gas} matrix, which is similar to Generation Shift Factor (GSF_e) in the DC power flow model:

$$F_{mj} = \sum_{i=1}^{NG} GSF_{gas,i,mj} * (S_i - GL_i) \tag{5}$$

$$\left| F_{mj} \right| \le Limit_{gas,mj} \tag{6}$$

Pipeline flow limit is shown in Eq. (6).

3) ***Compressor:*** Pressure loss occurs when natural gas flows through pipelines. Compressor stations are built to increase transmission efficiency and maintain the pressure levels of pipelines. In this paper, compressors are considered as ideal gas transformers, which increase the pressure with no power assumptions.

3. ED Model for Integrated Natural Gas and Electricity System

3.1. Objective function

The objective function depicted in Eq. (7) is to minimize power system operating costs consist of coal-fired generating unit operating costs and NGFGU operating costs. NGFGU operating costs are considered as gas purchase costs. Coal-fired generating unit operating costs are shown as Eq. (8).

$$Min \sum_{t}^{NT} \left[\sum_{n \in NG}^{NG} Pr_{gas} \cdot \eta_n \cdot P_{n,t} + \sum_{n \notin NG}^{NC} F_c(P_{n,t}) \right] \tag{7}$$

$$F_c(P_{n,t}) = a_n \cdot P_{n,t}^{\ 2} + b_n \cdot P_{n,t} + c_n \tag{8}$$

3.2. Constraints

1) Electrical power balance:

$$\sum_{n \in NG}^{NG} P_{n,t} + \sum_{n \notin NG}^{NC} P_{n,t} = \sum_{b}^{NB} D_b \tag{9}$$

2) Generation Constraint:

$$P_{n,\min} \le P_{n,t} \le P_{n,\max} \tag{10}$$

3) Generating Unit Ramp Rate Constraints:

$$P_{\mathrm{n},\ t} \text{-} P_{\mathrm{n},\ t-1} \le RU_n \Delta T \tag{11}$$

$$P_{\mathrm{n},\ t\text{-}1} \text{-} P_{\mathrm{n},\ t} \le RD_{\mathrm{n}} \Delta T \tag{12}$$

4) Reserve Constraint:

$$\sum_{n}^{N} (P_{\mathrm{n,max}} \text{-} P_{\mathrm{n},t}) \ge RES_t \tag{13}$$

5) Power Transmission Constraint:

$$\sum_{b=1}^{NB} GSF_{e,b,br} \times (P_b - D_b) \le Limit_{e,br} \tag{14}$$

6) Natural Gas System Constraints: Eq. (1) ~ (6).

4. Case Study

A case consists of an IEEE 30-bus system with a seven-node gas system is carried out, in which three of the six generators are set to be NGFGU. All the formulation and algorithms were implemented in GAMS and the optimization was carried out by using SNOPT.

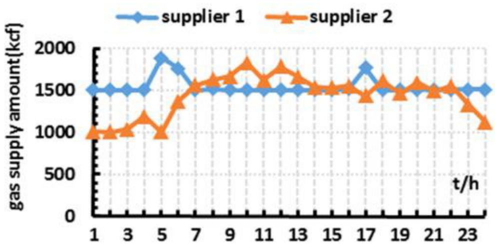

Fig. 2. Gas supply without pipeline transmission limit

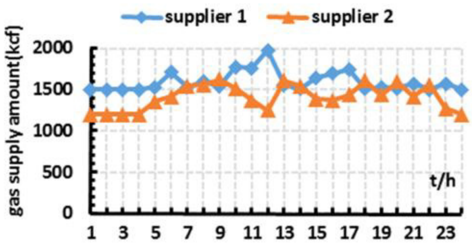

Fig. 3. Gas supply with pipeline transmission limit

Gas supplies with and without pipeline flow limit are shown in Figure 2 and Figure 3. Power generation results with and without pipeline flow limit are as shown in Table 1.

Table 1 Dispatch results for three periods

Unit	Power dispatch results within 1h-3h(MW)					
	With pipeline limit			Without pipeline limit		
1	63.30	61.78	66.22	67.99	67.99	69.07
2	31.24	31.24	31.24	31.24	31.24	31.24
3	46.76	47.16	46.09	55.00	55.00	54.01
4	25.00	24.96	25.03	20.84	19.68	22.30
5	53.71	53.63	53.76	42.58	42.20	43.85
6	27.65	27.49	27.97	30.01	30.15	29.84

From Fig.2 and Fig 3, it can be seen that the pipeline flow limit can result in different gas supply distribution between the gas suppliers. As Table 1 shows, dispatch results are different within the schedule time 1h-3h, which demonstrates that the pipeline flow limit can influence the economic dispatch results.

5. Conclusions

This paper proposes a security-constrained ED model for integrated natural gas and electricity systems. The natural gas system model is presented, and security constraints of both systems are considered in the ED model. The GSF_{gas} matrix similar to GSF_{e} in the DC power flow model is defined to replace the node gas flow balance equation. The case study results demonstrate the effectiveness of the proposed model.

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